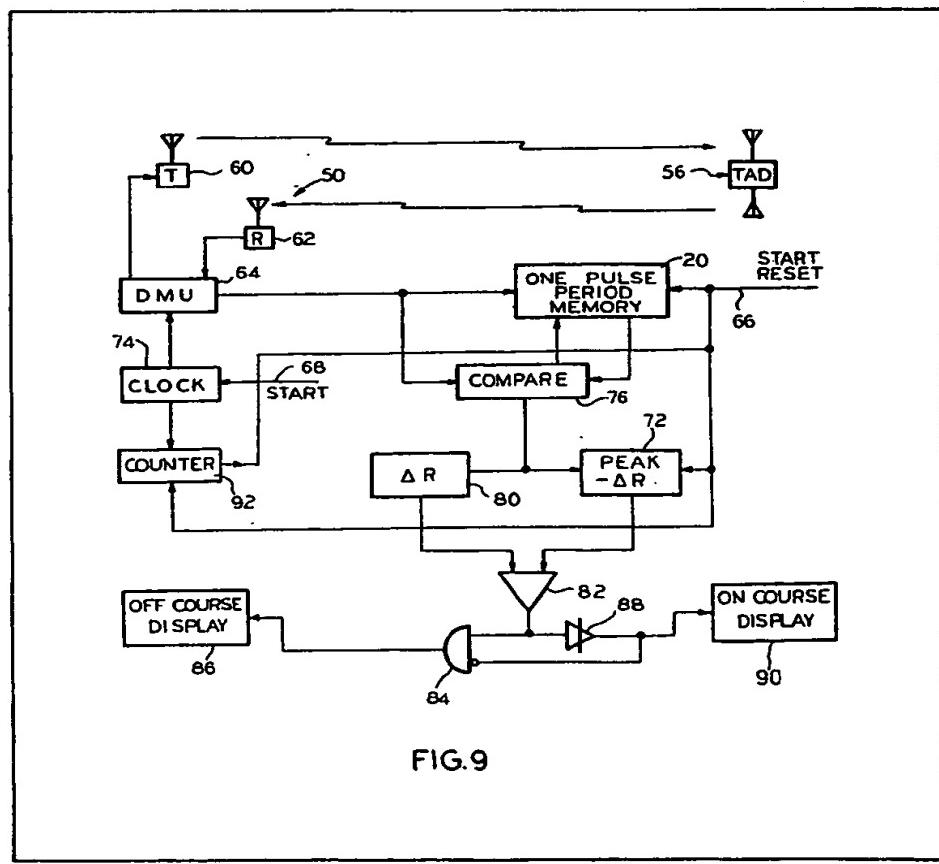


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(54) Means for and methods of homing under radar signals
(57) A radar or sonar guide homing system for aircraft, ships, etc., makes periodic distance measurements between a stationary transponder location (56) and a mobile interrogator location (50). An "on course" signal (90) is given when the difference ΔR between successive measurement readings is maximized, in a negative direction (i.e., the gap between the stationary and mobile locations is closing). Otherwise an "off-course" signal (86) is given. An "S-turn" maneuver confirms the accuracy of the readings.



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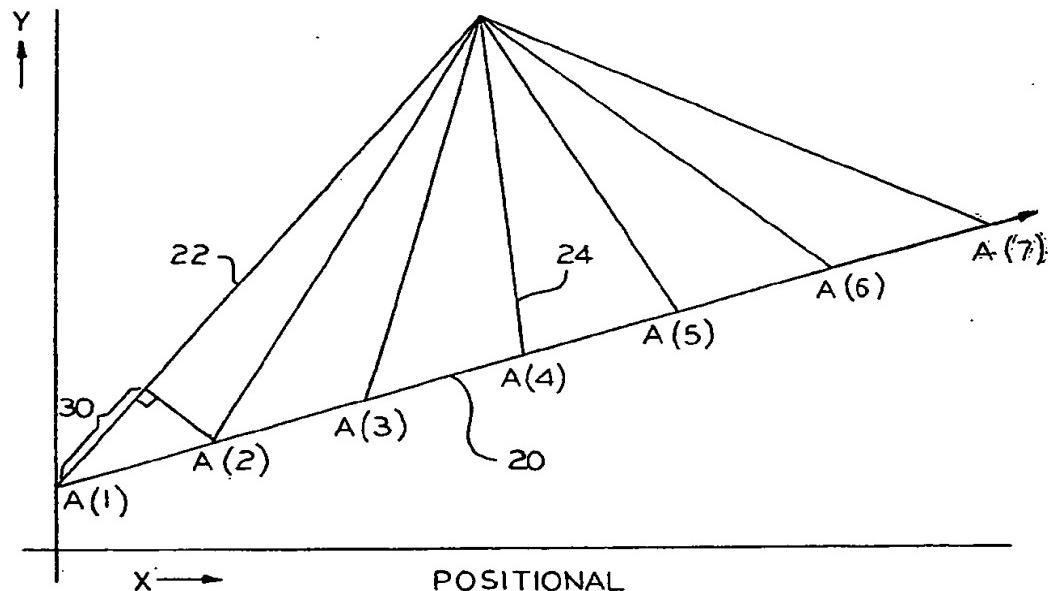


FIG.1

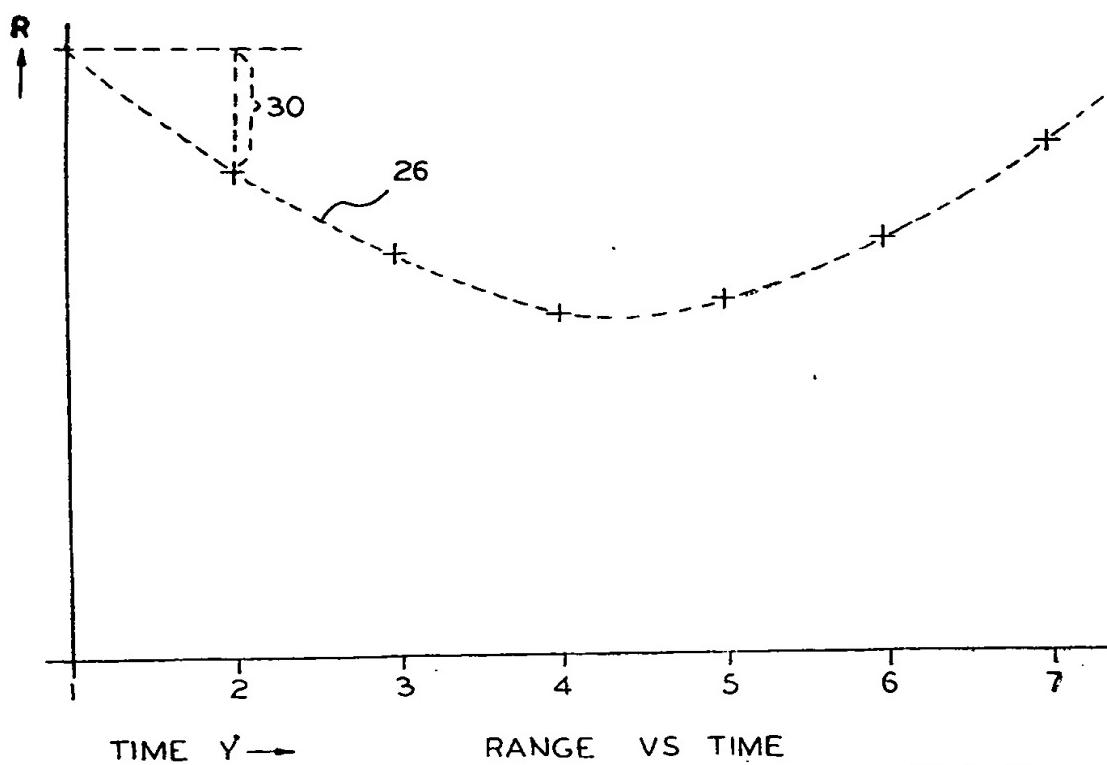


FIG.2

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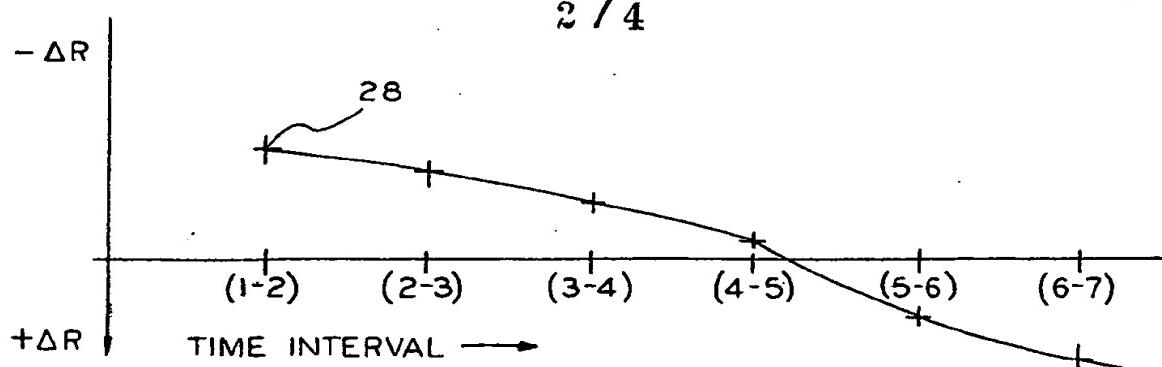


FIG. 3

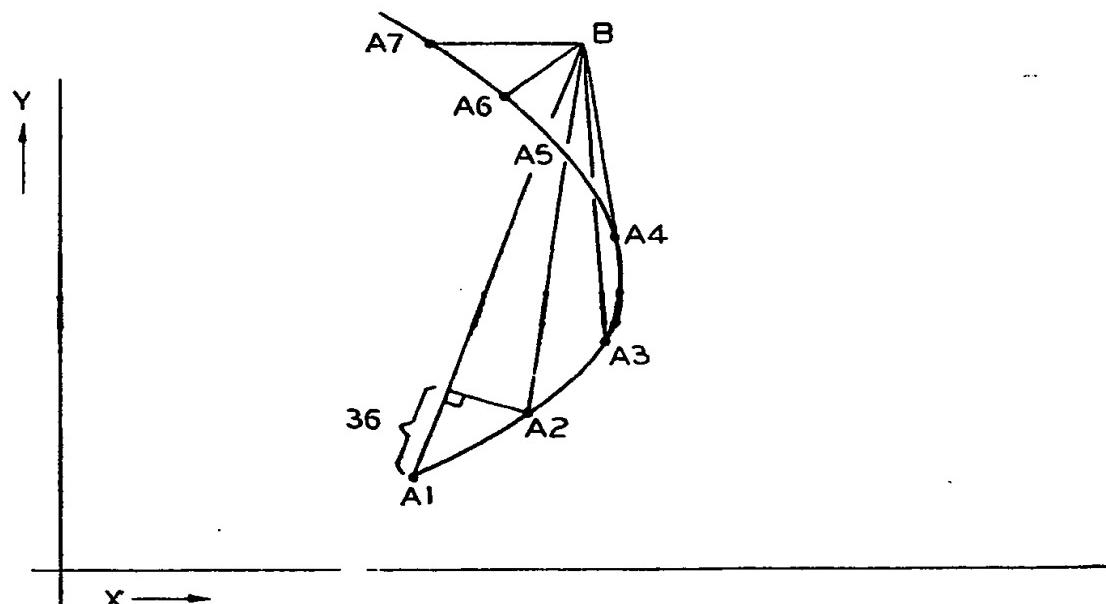


FIG. 4

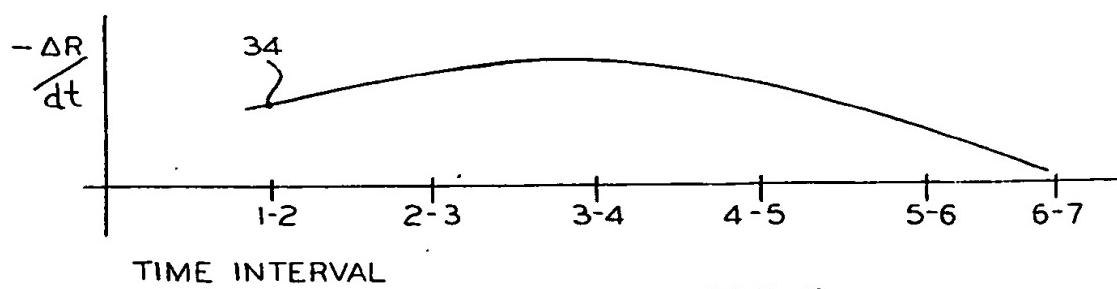


FIG. 5

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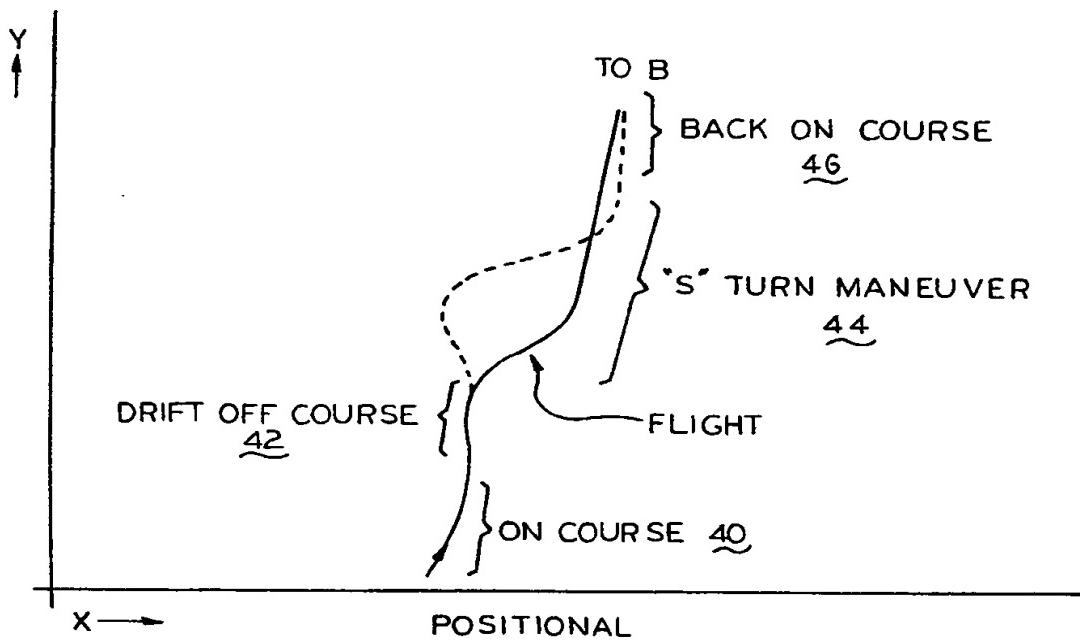


FIG.6

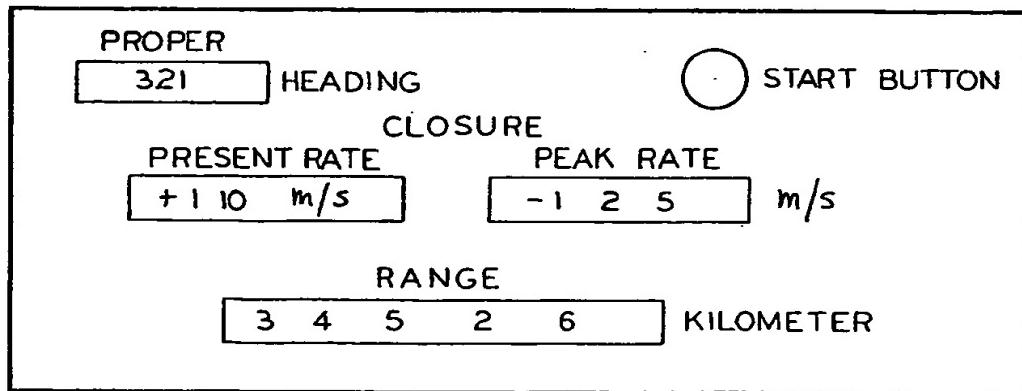


FIG.7

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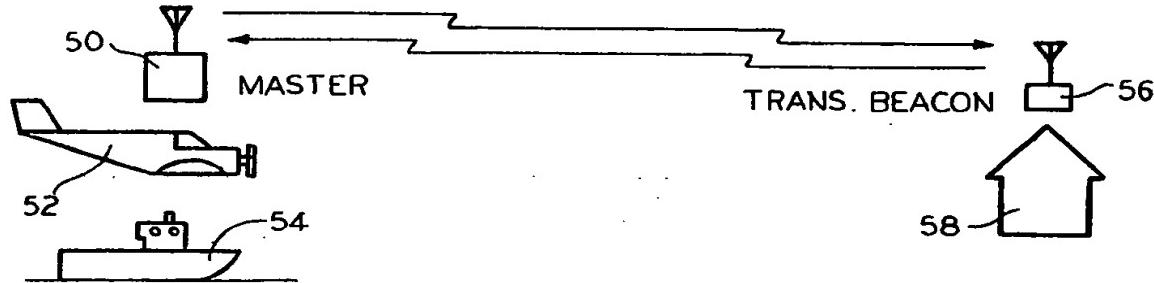


FIG. 8

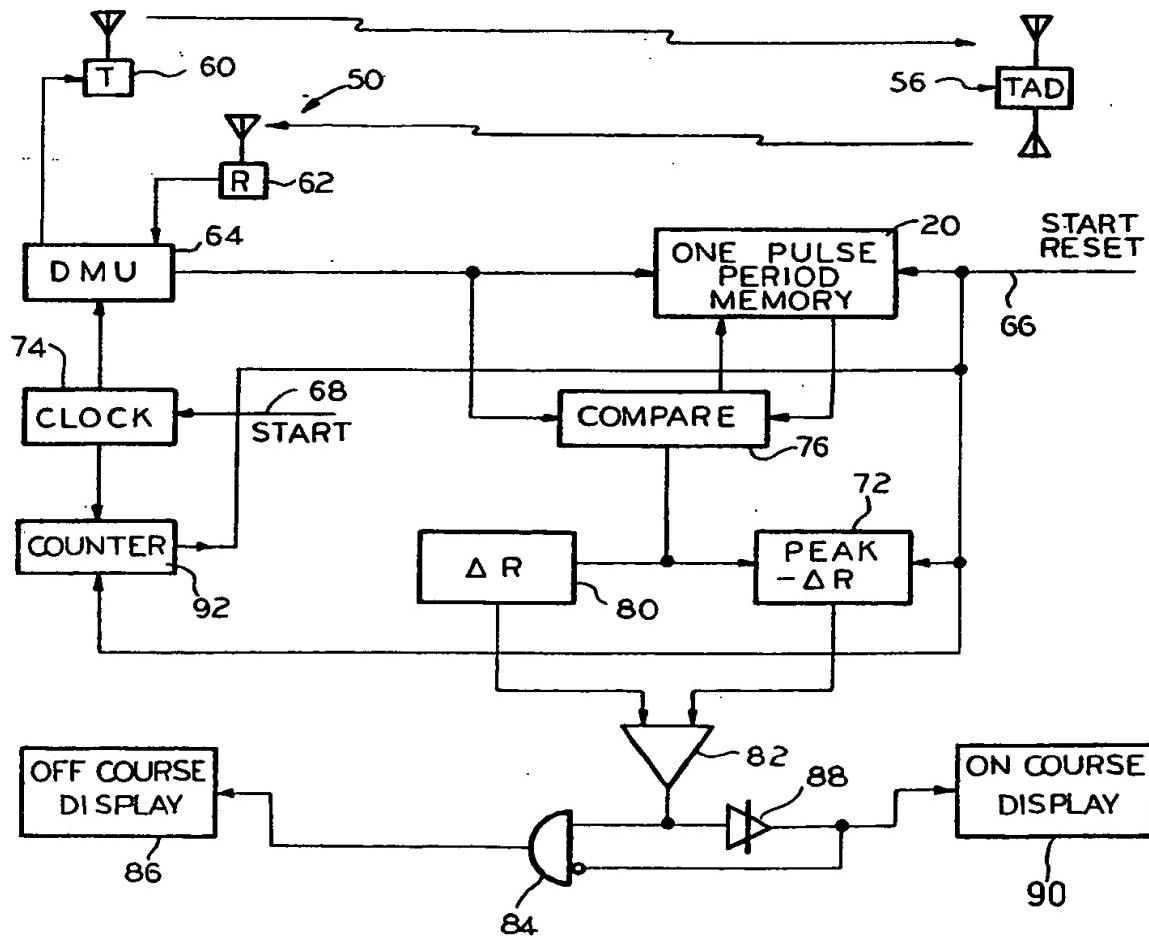


FIG. 9

SPECIFICATION**Means for and methods of homing under radar signals**

- 5 This invention relates to means for and methods of using radio navigation and distance measuring equipment, and more particularly to a use which enables a vehicle to home on a stationary transponder.
- 10 The invention is primarily described herein as being used on an airplane. However, it may be used on any of many other vehicles, also. Thus the word "airplane" is to be construed to include ships, boats, helicopters, and all similar vehicles. Also, the system is described
- 15 in conjunction with distance measuring systems which use radar signals. However, it should be apparent that it may also be used with other systems, such as a sonar system. Accordingly, the word "radar" should be construed to mean all similar and suitable systems.
- 20 There are many different kinds of systems for using radar signals to measure distances and to navigate. Usually, there are transmitters and receivers which send and receive radar pulses. Then, there are various
- 25 data processing units for manipulating the information picked up by or derived from the radar system. These data processing units drive display units and the system user is given a read out in terms of distances, azimuths, and the like. The resulting system
- 30 is usually relatively expensive.
- Most airplane or boat pilots do not really want or need all of the information which a conventional system gives. As a generality, most pilots merely want to have enough information to enable them to head
- 35 their vehicle toward a home base, and nothing more. The fact that they are a certain number of miles out may be irrelevant because there is nothing much that can be done about it. Likewise, most of the other information which a radar system gives relates to
- 40 things that are out of the pilot's immediate interest or control.
- Accordingly, an object of the invention is to provide means for and methods of homing, which requires a minimum amount of equipment. Another object is to
- 45 provide means for and methods of using almost any radio distance measuring equipment to home on.
- Still another object is to provide a method of homing which is adapted to use a minimum display, which merely tells a pilot when he is headed in a
- 50 correct direction.
- A method of homing on a beacon in a system using electrical or sound signals for measuring distances, said methods comprising the steps of:
- (a) mounting a distance measuring transmitter on a
- 55 vehicle which is to be guided to a home location;
- (b) mounting a transponder beacon at the home location to which the vehicle is to be guided;
- (c) periodically transmitting an interrogation pulse from said vehicle toward and receiving a reply pulse
- 60 from said transponder;
- (d) comparing the distance measured responsive to each interrogation and reply pulse with the distance last previously measured; and
- (e) directing said vehicle along a path which is
- 65 indicated by said comparing means as causing the

greatest negative change of distance measured between successive pulses.

While the inventive process may be used with many different kinds of radar, sonar, or like systems, it is here assumed that it is being used with a trilateral radar system disclosed in the following U.S. patents: Merrick 3,810,179, Parker 4,275,398 and Dano 3,938,146, hereinafter called the "Merrick system".

The invention will be explained with help of information set forth in the attached drawings in which:

Figure 1 is a schematic representation showing distance measurements along a straight path of an airplane relative, to the location of a transponder station;

Figure 2 is a graph setting forth information taken from Figure 1 which plots range vs. time, to show how the measurements peak when the vehicle is closest to the transponder;

Figure 3 is a graph which shows the change in range values $\frac{dR}{dt}$, taken from Figures 1, 2, and which shows that as the airplane approached the transponder beacon a polarity difference appears at the point of the airplane's closest approach;

Figure 4 graphically indicates how the distance measurements occur when the airplane follows a curved path;

Figure 5 is a graph which shows that there is a peak in range differences when the vehicle in Figure 4 is headed directly toward the beacon;

Figure 6 schematically represents an "S-turn" which may be followed by an airplane to verify its course, and explains how it corrects its path toward the beacon, if it drifts off course;

Figure 7 is a representation of one form of information which may be given to a pilot in a digital format;

Figure 8 schematically represents a system (such as the Merrick system) which incorporates the invention; and

Figure 9 is a block diagram of the equipment used to practice in the invention in the system in Figure 8.

A first observation is that, when an aircraft or a boat is headed for a particular place, it moves at a remarkably constant speed. All of the same environmental factors (wind direction, velocity, etc.) tends

to be stable over a substantial period of time. The throttle is placed at some position and not moved thereafter. Consequently, if the airspeed appears to change relative to some fixed point, it probably means that the vehicle has changed its direction. From

elementary trigonometry, it is seen that: Velocity_{perceived} = Velocity_{true} × cosine ϕ where: ϕ is the angle between the actual flight path and the most direct path to a home base. If the angle is 0°, the cosine is one; if it is 2°, the cosine is 0.99939, which is less than one part in a thousand. However, if the readings are repeated every one second, for example, the difference between the readings is relatively large and change is easily detected. Therefore, even a slight change in

course is easily detected when the periodic difference is analyzed.

These principles may be applied to and explained by the graphical presentations in the attached figures. More particularly, Figure 1 shows the straight path followed by an airplane travelling along the line 20.

The transponder beacon is located at point B. At regular time intervals, a distance measuring unit aboard the airplane sends a radar pulse and takes a distance reading to the transponder beacon B (seven readings A(1) -A(7) being shown in Figure 1).

- At reading A(1) the airplane receives a distance indication represented by the length of line 22. During each of the succeeding readings A(2), A(3), A(4), the distance to beacon B is found to be getting shorter.
- Between the readings A(4) and A(5), the airplane has reached the closest point to transponder beacon B. Then, the distance becomes progressively longer on each of the succeeding readings A(6)-A(7).

If the ranges R or lengths of the various lines A(1) to A(7) are plotted on a uniform time scale (Figure 2), there is a U-shaped curve with a minimum at the location between points 4 and 5 which is closest to the transponder beacon B. By comparison, it is seen that the Figure 2 minimum between times "4", "5", corresponds to the shortest distance in Figure 1. Thus, it is found that an aircraft will be headed straight for the beacon if it always flies at the minimum or point of curve inflection between the time periods "4" and "5".

If the Y-axis positions or coordinates of each of the points on curve 26 is subtracted from the Y-axis position or coordinate of the next succeeding point, one can plot the difference between successive measurements, which is seen in Figure 3. Thus, point 28, for example, represents the length of the line 30 in Figure 2, which is the difference between the distances measured at times A(1) and A(2). This difference may be called the " ΔR " or change in range. As long as the aircraft is approaching the beacon B (Figure 1), the ΔR distances are reducing or progressively moving from a more negative to a less negative value as shown in Figure 3. When the aircraft passes its closest point and begins to move away from the beacon, the ΔR distances start to increase and become progressively more positive. The ΔR crosses the zero axis between time periods "4" and "5," which conforms to the teachings of Figures 1 and 2.

Figures 1 - 3 consider the manner in which the ranges change when the airplane moves along a straight line. Next, to be considered is the manner of range changes, when the aircraft follows a curving path 32 (Figure 4).

If the same reasoning is followed that was explained above with respect to Figures 1 - 3, the airplane periodically takes a distance reading to the beacon B (Figure 4). Common sense tells one that the maximum velocity between the airplane and the beacon occurs when the airplane is flying directly toward the beacon between time periods A(3) and A(4). This observation is confirmed in Figure 5 when the differences in range ΔR is plotted against time. The Y-axis position of point 34 represents the distance 36 in Figure 4 (i.e., the difference in measured distances in time periods A(1) and A(2)). Again, there is a peak in Figure 5 when the airplane is proceeding directly toward the beacon B.

Hence, the conclusion is drawn that the airplane should always be flown to maintain it at the peak point on the ΔR_{dt} curve of both Figure 2 and Figure 5. Therefore, all that is required is to provide a distance measuring device which operates periodically (say once every second) and a memory which enables a

recognition of whether the ΔR value is increasing or decreasing and which gives a signal when the ΔR is a maximum value as compared to preceding values.

The pilot needs to have a way of verifying the maximum readings, which is shown in Figure 6. For example, unknown to the pilot, he encounters a strong side wind which drives the airplane off course in path segment 42. Accordingly, despite the fact that the airplane is always headed in the same direction, it is no longer moving directly toward the beacon. Therefore, the pilot occasionally wants to reorient his airplane to determine whether he is truly following a path which gives a maximum ΔR_{dt} reading.

In greater detail, some point before the graph of Figure 6 begins, the pilot flies along some course and receives readings which put him on a course leading toward the beacon. When Figure 6 opens, the airplane is on a course in path segment 40 which is headed toward the beacon. Near the end of this straight path (42), the wind blows the airplane off course. Accordingly, to verify the course in path segment 44, the pilot turns the airplane either left (dashed line) or right (solid line). During this turn, the distance measurements are as shown in Figures 4 and 5. By seeking the maximum ΔR_{dt} (Figure 5), the airplane is brought back on course in path segment 46.

It should now be obvious that only a distance measuring radar device and a simple calculator type of device is required to practice the invention. Since the invention may be practised with almost any distance measuring device, very often all that is required is a small add-on unit coupled to a distance measuring part of another system. That other system may still perform its primary function.

For most needs, the calculator type device merely subtracts one value from another and recognizes the highest value among the subtractions. It may simply be connected to operate visual indicators which indicate either the highest value or not the highest value. For example, a light may be green when the unit indicates that a maximum ΔR_{dt} is being received and red when less than a maximum is being received. Thus, in the "S-turn" of Figure 6, the light appears green during path segments 40, 42. It is green in segment 42 because the preceding readings do not change enough to create a new maximum difference. When the pilot turns off course in the "S-turn" maneuver of path segment 44, the light becomes red until the new maximum is read, and then it again becomes green.

Without adding too much cost, the calculator part of the system may be connected to give a digital readout. Figure 7 exemplifies one such read out. Arbitrarily, Figure 7 is drawn to show that the last time that a maximum reading was set, the aircraft was on a compass course of 321°. The aircraft was then travelling away from the beacon at a rate of +110 meters/second (note the "+" mark which indicates that the gap is opening). The greatest (most negative) rate of change occurred when the aircraft was travelling at a peak rate of -125 meters/second (the "-" mark indicates that the gap is closing). The apparent range to the transponder is 34.526 kilometers.

Whenever the pilot wants to go forward the

transponder, he pushes the "Start Button" and follows the procedures outlined above. He flies a course which makes his "present rate" the most negative number that he can achieve. For example, as 5 he circles the airplane, the highest number achieved is -125 meters/second. If he brings his "present rate" to -125 meters/second, he is headed directly toward the beacon. As he corrects his course, it is conceivable that the peak rate number could increase in the 10 negative direction. If so, he would keep his "present rate" meter on that new and more negative number.

The main value of the digital read out is that it becomes easier to program a path toward the beacon since the user knows the actual peak rate which is 15 found while the airplane is circling. Therefore there can be less for turning in the S-turn maneuver to test for path accuracy, as explained with Figure 6.

Figure 8 shows an exemplary installation using parts of the above-identified Merrick trilateral radar system, although the invention is not necessarily limited to use with this particular system. As here shown, the distance measuring parts 50 of a mobile master station are mounted on either an airplane 52 or boat 54. A stationary transponder beacon 56 is 20 mounted at a remote location 58, which may be an airport building or a boat house, for example. The vehicle mounted mobile equipment 50 periodically transmits a pulse (say about once a second) and the stationary transponder 56 sends a reply pulse in 25 response thereto.

The term "transmits a pulse" must be construed in the light of the system being used. In Merrick's above identified trilateral radar system, literally thousands of pulses might be sent to receive one "good distance 30 reading." Some times a number of good readings are taken to ensure reliability through redundancy. At the electronic speeds of the system, this reading corresponds to one of the readings A(1) - A(7) in Figures 1, 4. In any event, each good reading is herein described by 35 the term "transmits a pulse" or the like. The object of the system is to guide the mobile equipment on airplane 52 or the boat 54 to the stationary equipment 56 at location 58. The master station 50 comprises a transmitter 60, receiver 62, and distance measuring unit 64, which are parts of the above identified Merrick trilateral radar system. The master station 50 causes 40 the transmitter 60 to send an interrogation pulse to the transponder 56, while banking receiver 62 to prevent it from responding directly to the transmitted pulse. The transponder beacon 56 receives the pulse and introduces a turn-around delay ("TAD") period, during 45 which the master station 50 removes the blanking from the receiver 52. After the TAD period, the transponder 56 sends a reply pulse to the receiver 62.

50 The distance measuring unit 64 measures the duration of the time period required for the round trip of the interrogation and reply pulse, subtracts the TAD period and indicates the distance between the two stations 50, 56.

55 The remainder of the equipment in Figure 9 is added to the Merrick system, according to the invention. To initiate the system, a "Start Button" (Figure 7) is pushed to mark wires 66, 68 in Figure 9. The marking on wire 66 resets to zero a one-pulse period memory 60, the remainder of the equipment in Figure 9 is added to the Merrick system, according to the invention. To initiate the system, a "Start Button" (Figure 7) is pushed to mark wires 66, 68 in Figure 9. The marking on wire 66 resets to zero a one-pulse period memory

65 70, a peak ΔR memory 72, and a counter 92. The

marking on wire 68 starts a free running clock 74, which measures about a second, which is the interval between the successive readings A(1) - A(7). Thus, every time that the clock 74 releases a clock pulse, a different one of the readings A(1) - A(7) is taken. Meanwhile, the Merrick trilateral or other system may be carrying on any other function which it is designed to perform.

Each time that the distance measuring unit 64 gives 70 a distance reading responsive to clock 74, that distance reading is stored in one-pulse period memory 70 and simultaneously sent to a compare circuit 76. The compare circuit 76 finds the different (" ΔR ") between the present distance reading and the immediately preceding reading, after which memory 70 is reset to store the present reading. Any suitable buffer storage may be used to preclude a possible loss of the present reading pending the reset.

The difference reading ΔR is stored in memories 72, 75 80. The memory 72 can increase its stored reading in a negative direction, but it cannot reduce that stored reading prior to a system reset. The negative reading means that the gap is closing between the mobile and stationary stations 50, 56. A positive reading indicates 90 that the gap is opening.

The outputs of the ΔR circuit 80 and the peak- ΔR memory circuit 72 are fed into a difference amplifier 82, which may be adapted to accept any predetermined tolerance of differences. If there is an output 95 from the difference amplifier 82, a signal feeds through an inhibit gate 84 to activate any suitable off-course display 86 (such as a red light, for example). An inverter 88 is turned off by the output from the difference amplifier. If there is no difference in the

outputs from the circuits 80, 72, there is no output from the difference amplifier 82, and inverter 88 turns 100 on. Gate 84 is inhibited to prevent any off course display at 86. On course display 90 (e.g., a green light) is turned on and the pilot knows that he is on course.

105 An optional counter 92 counts a number of pulses from clock 74 and then resets itself and the memories 70, 72. When the peak- ΔR memory 72 resets, the difference amplifier 82 gives an output signal which causes the off-course display 86 to come on. The pilot seeing this, changes his course slightly, thereby

110 instinctively going through an S-turn maneuver of Figure 6. As he does so, the peak- ΔR circuit 72 takes a new maximum reading, thereby correcting for any drift in the airplane course (as when a side wind deflects the airplane from its apparent course).

115 The important thing for the pilot to do is keep his airplane on one side of the beacon. Therefore, he is always closing the gap between his airplane and the beacon. If he overflies the beacon, the gap begins to open, in what appears to be an almost random manner. Then, he will have to start the procedure all over, pushing his start button and circling to find the best course.

120 Those who are skilled in the art will readily perceive how to modify the inventive method. Therefore, the appended claims are to be construed to cover all equivalents falling within the scope and the spirit of the invention.

CLAIMS

130 1. A method of homing on a beacon in a system

- using electrical or sound signals for measuring distances, said method comprising the steps of:
- (a) mounting a distance measuring transmitter on a vehicle which is to be guided to a home location;
 - 5 (b) mounting a transponder beacon at the home location to which the vehicle is to be guided;
 - (c) periodically transmitting an interrogation pulse from said vehicle toward and receiving a reply pulse from said transponder;
 - 10 (d) comparing the distance measured responsive to each interrogation and reply pulse with the distance last previously measured; and
 - (e) directing said vehicle along a path which is indicated by said comparing means as causing the
 - 15 greatest negative change of distance measured between successive pulses.
2. The method of claim 1 and the added step of periodically maneuvering said vehicle through an S-turn to verify its course heading.
- 20 3. A homing system comprising mobile means for sending distance measuring interrogation signals, stationary means for returning a reply signal responsive to said interrogation signals, means responsive to timing an interval between said interrogation and said
- 25 reply signals for indicating the distance between said mobile and stationary means, means for periodically initiating said sending of said interrogation signals, whereby there are periodic distance measurements, means responsive to each successive periodic dis-
- 30 tance measurement for detecting the range difference between each successive one of said distance measurements, and means responsive to the detected difference for indicating a maximum range difference when said mobile means is travelling toward said
- 35 stationary means.
4. The homing system of claim 3 and means for storing a memory of the maximum difference which is indicated while the mobile means is circling to find the best path toward the stationary means for indicating
- 40 whether the present range difference is equal to or less than said maximum difference.
5. The homing system of claim 3 and means responsive to said range difference for giving a $+ \Delta R$ signal when said mobile means is moving away from
- 45 said stationary means and a $- \Delta R$ signal when said mobile means is moving toward said stationary means.
6. The homing system of claim 5 and means for storing a memory of the peak- ΔR signal, and means
- 50 for matching a present ΔR signal with the stored peak- ΔR signal.
7. The homing system of claim 6 and means for giving an off-course signal when said present ΔR signal does not match said stored- ΔR signal.
- 55 8. The homing system of claim 6 and means for giving an on course signal when said present ΔR signal matches said stored- ΔR signal.
9. The homing system of any one of the claims 6-8 and means for periodically resetting said stored
- 60 memory of said peak- ΔR signal.
10. A homing system substantially as described herein with reference to and as illustrated in Figure 8 of the accompanying drawings.
11. A homing system substantially as described
- 65 herein with reference to and as illustrated in Figure 9

of the accompanying drawings.

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